Transactions of the I·R·E

Professional Group on Vehicular Communications

Symposium on
WHAT'S NEW IN MOBILE RADIO

Presented under the sponsorship of
IRE Professional Group on Vehicular Communications
at the 1952 IRE National Convention
New York, N. Y.
March 6, 1952

Price per copy—

Members of the IRE Professional Group
on Vehicular Communications—$1.20
Members of the IRE—$1.80
Nonmembers—$3.60

Lithoprinted in the United States of America

VC—2

AUGUST, 1952

The Institute of Radio Engineers

TRANSACTIONS OF THE IRE

Professional Group on Vehicular Communications

PGVC-2

August, 1952

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MOBILE RADIO PROBLEMS RESULTING FROM NEW TECHNIQUES

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As in most fields, mobile radio problems arise not only from new radio techniques, but also from new non-radio techniques. The radio engineer is continually developing new methods for using existing frequencies and new means for utilizing portions of the radio spectrum, previously inaccessible because of technical barriers. Each new development finds application as an incidental and integral part of many operations which are widely removed from the communication purposes. These applications in turn engender new demands on the radio industry and the cycle of progress moves on. It is the purpose of this paper to point out a few of the communication problems that have arisen and trends which will, in all probability, introduce new communication headaches which we, as radio engineers, must eliminate.

There are three broad divisions in the field of mobile communications -- the marine, the air, and the land mobile services.

Probably no one knows whether primitive man first took a load off his back and placed it on a log to cross a stream, or placed it on some branches to be dragged behind. We do know the canoe antedates the wheel and that the use of ships is one of the most venerable forms of transportation. The marine industry was the first user of mobile radio communications and its problems will be discussed first.

In the beginning, the marine radio problems were few and far between. The general frequency for distress and calling was 600 meters and 300 meters was provided for the benefit of the small vessel which could not support a sufficiently large radiating system to use 600 meters efficiently. In due course, it was found that communications on 300 meters was not satisfactory due in part to a higher noise to signal ratio and to less efficiency in the equipment then available in generating the higher frequency. In addition, only telegraphy was available for use. The larger vessels could support not only a large antenna but also the cost of the radio operator. For these reasons the small boat for years went its merry way without the benefit of ship to shore or ship to ship radio communications.

With the development of marine radio telephony on the high frequencies, the small vessel again became interested and there was considerable growth in the number of ship and shore radio telephone stations on the 2 mc band. During this same period, the larger vessels occupied the high frequencies in increasing numbers both for long distance telegraphy and telephony.

In the reallocation of frequencies by the International Radio Conference held in Atlantic City in 1947, the developments in the marine use of high frequencies were recognized, and frequencies were set aside for the short distance requirements of the small boat, as well as for long distance marine radiotelegraphy and long distance radiotelephony.

At the International Extraordinary Administrative Radio Conference just concluded in Geneva, plans for the utilization of the high frequencies in accordance with the terms of the Atlantic City Radio Agreement were approved. The problem now is to get the present non-marine occupants off the new marine frequencies and into their own bands and then to secure the marine radio equipment for operation on the new frequencies under the new standards.

As yet, only about 28,000 of the 464,000 small craft in the United States are equipped for radio communication. Even this relatively small number has served to introduce various problems. The frequencies, heretofore available, nowhere near approach the capacity required to handle the amount of traffic which is generated during normal operation by these vessels. The additional frequencies in the 2 mc band to become available under the Atlantic City agreement should relieve the congestion in part.

Provision was recently made by the FCC in its rules and regulations for the use of a number of VHF frequencies which should also help the situation. Before the VHF frequencies can come into general use, however, it is necessary for engineers to design, and manufacturers to construct, equipment suitable for these vessels which can be sold at a price commensurate with the figure being paid for the vessels themselves. Even with the best of equipment and full use of all potentially available frequencies, there will remain serious congestion unless the users themselves take steps to improve the standard of operation.

One needs only to listen for a short while to the traffic now being handled on the 2 mc ship frequencies to appreciate the volume of unnecessary communication being transmitted. In the marine field, as distinct from all the other mobile fields, each mobile unit is essentially a little empire unto itself, subject, as a practical matter, to the whim of the master. For the most part, the small boat operator has had no contact with two-way radio except on his boat. All too often he does not appreciate that he is on a party line; that there is a shortage of frequencies, and that he should not talk when he has nothing to say. The various yacht clubs, marine associations, and industrial groups should actively carry on a program of education along these lines.

The aviation industry, one of the youngsters in the transportation field, is less than 50 years old and aviation communication is much younger. In spite of its relatively tender age, the American aviation communications system is one of the most efficient and modern of any of the industrial mobile communications systems in the world. Even though this be true, the communications problems of the aviation service are many and the way to their solution is only seen in part.

Perusal of Special Committee 31 of the Radio Technical Commission for Aeronautics, and copies of the subsequent reports on the same subject, will provide abundant opportunity for the exercise of inventive talent both from technical and operational standpoints. In the 15-year program which that committee recommends, and which will lead to an all-weather air traffic system to permit the navigation of aircraft without delay and without regard to the state of the weather, communication plays a major role.

In the land mobile field, the problems are those which generally arise when you have more customers than you have supplies. For all practical purposes, the land mobile service did not start to grow until transmitting equipment was

built for operation above 30 mcs. While there were a few pioneer two-way installations on mobile vehicles for special purposes on lower frequencies, they were in general cumbersome, inefficient and unsatisfactory. As a result, the service was restricted to a dispatching service in which the cars were equipped with receivers alone. Due to insufficient spectrum space, the authority to use these one way systems was severely restricted and only those groups which were able to convince the FCC that their service involved safety of life and property were able to receive authorization.

With the development of equipment making use of frequencies above 30 mcs practicable equipment was installed on vehicles and the advantages of two-way land mobile communications were explored. The police were probably the first to enter and exploit this field to any great extent. They found that the efficiency of the police force could be increased enormously if the police executive officer could, at all times, be in direct communication with his forces. The success of the police in this field generated a great deal of interest in mobile two-way radio on the part of other groups. The public safety services were recognized, and a few industrial services were authorized. However, up to the beginning of the last World War, the Commission was very cautious in allowing new services to enter the two-way radio communications field. The public safety services alone were crowding the portions of the spectrum for which commercial equipment was then available.

The new techniques developed during the last World War made possible the utilization of additional portions of the radio spectrum. People in the United States are talkative, and generally prefer to exchange ideas by word of mouth. As a result, every time a new means of voice communication is open, many, many, people wish to avail themselves of the facility. The Commission was requested to, and did authorize many new services. Today, two-way voice radio is an integral part of most of our industries. Additionally, through the common carrier mobile service, and through the amateur and citizens radio, it is available to practically everyone.

The VHF spectrum is already crowded and again we are exploring means of handling more communications. Recently, the 450 mc band has been opened for land mobile use. This band looks most promising, and, for a time, may relieve congestion. At present, the equipment for this band is in short supply and is relatively expensive. With increasing production the price should come down and it may not be very long before this band also will be crowded.

The potential market for two-way land mobile radio is great. All information presently available indicates that the cost of a two-way radio installation including first cost and maintenance, is sufficiently high to restrict its use to situations where economic or safety reasons, or both, justify considerable expenditure. Those persons who have occasion in the conduct of their business to (1) redirect their vehicles from time to time during the day, as in the taxicab business and various types of repair and service businesses, or (2), consult between office and car, or between two or more cars, as in the case of physicians and companies having roving or scattered supervisory employees, or (3), obtain information promptly from the vehicle occupant, as in the case of newspaper reporters, or (4), to coordinate action at two or more physically separated points, as in cable-pulling or wire-stringing operations by electric and telephone utilities, are potential users. The person who does not require frequent communication between vehicle operator and its base may find it difficult to justify the substantial expenditures involved in installing mobile communication facilities.

The "Citizens Radio" was established as a service in an effort to meet this cost question and enlarge the use of radio. However, there has been very little development in that part of citizens radio which might be termed "every man's radio." Basically, this service was established in the 460-470 mc band for use by the non-technical person on a mass-use basis with no interference protection as between users of this service. For this reason, it seems necessary for the Commission to maintain relatively close control over the design of equipment proposed to be used lest it stray off frequency and cause untold interference to services on adjacent frequency bands. This is done by requiring that it be demonstrated that the equipment will meet published standards. There are a number of equipments which have met Class B type approval tests. (These are the low power hand portable walkie-talkie types of equipment). Nonetheless, they have never been placed in production, possibly because they cannot be sold at a price which the manufacturer believes the average man is willing to pay. Vehicular equipment, such as is used in the regular services (termed Class A equipment), is beginning to be sold to organizations who are ineligible for the usual services but who have a substantial communication need which can be satisfied by a relatively low grade of service. For instance, the newspaper desiring to maintain communication with the trucks of its Circulation Department, laundry and dry cleaning concerns, undertaking establishments, and a host of miscellaneous commercial and residential service businesses. There also have been a number of control devices type approved. For example, garage door openers, which have been placed in production and are being sold under Class B type approval certificates. Even though "every man's radio" has not become an accomplished fact, it is believed that providing for a "citizens radio service" was a sound concept.

World War I brought the vacuum tube out of the laboratory making practicable the generation of the higher frequencies, sensitive receivers, and voice modulation. World War II broadened the horizons frequency wise, put pulse techniques into regular service, and provided many other technical tools. Efforts to avoid a third World War are placing almost as much strain on our inventive ability as being involved in such a catastrophe. We are faced with unprecedented demands for communications. There is no question but that the communication industry will develop hitherto undreamed of devices to the end that these demands will be met.

Since we cannot build new frequency spectra, we must do the best we can with the one we have. Engineers face a continuing problem to wring from that spectrum the greatest possible use for the greatest possible number. The research engineer must seek new avenues of approach to old problems. The development engineer must design equipment which occupies less spectrum space without undue sacrifice of performance in other respects and without introducing refinements which increase equipment costs. The manufacturer must continually improve standards lest the engineer's efforts in design be destroyed by marketing equipment that will not measure up to requisite standards. The systems engineer and the consulting engineer must devise installations with a view to spectrum economy and interference control in addition to the usual factors of cost, simplicity and serviceability. The user of the radio system must devise operating and maintenance procedures and exploit every possible way to assure the rapid and accurate transmission of the maximum of information with a minimum occupancy of radio time.

This situation offers a challenge to all radio engineers and with their help the communications business of the world will continue to be conducted in spite of complaints of congested channels, interference and shortage of frequencies.

VOICE FREQUENCY TONE SIGNALLING

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In the Radio Communication field, the need for selective signalling devices has been recognized for the past several years, and many devices have been developed to satisfy the need. The devices which are described in this paper are the result of market analysis, experiment, and extensive field testing to make a system of voice-frequency, tone-signalling apparatus which fills substantially the need.

All such developments traverse a similar path, horse-sense analysis plus empirical ideas, thru controlled experiment followed by formulation of a theory. When the process is repeated often enough, theoretical details are corroborated by experiment. The essential characteristics for a signalling system to be applied to Radio Communications systems were so developed.

1. The signals must be transmitted equally well over wire-line telephone-exchange facilities and radio-frequency transmission paths.

2. The signal should consist of audio tones in which only the frequency is used as a distinguishing characteristic.

3. The tone frequencies used must lie within the voice-frequency range 300-3000cps, in order to be usable over normal telephone circuits and to comply with International Radio regulations.

4. Because of the vagaries of rf propagation, the signal should be completed in less than 0.5 seconds to insure reliable operation.

5. Since the tone signals must be in the voice band, there is a finite probability of simulation of the tone signals by voice. "Voice triggering" must be minimized by highly selective circuits and time-constants of the proper magnitude to comply with (4). Experimentally, it has been found that a circuit "Q" of approximately 200 and an integration time of the order of 0.1 second reduce the probability of "voice-triggering" to negligible values.

6. The Intermodulation Distortion of typical communication systems is very high so that the use of simultaneous tones should be avoided. The intermodulation process readily creates sum and difference frequencies which thereby generate false signals. When the investigation began this was only a subjective impression; - later confirmed by measurements on typical systems. As a consequence, single or sequential tones should be used for selection.

7. Communication receivers of different manufacture tend to considerable uniformity at the output of the audio detector so the signal should be derived from this point. A further advantage of this point of "take-off" is the independence of volume control and squelch settings which would otherwise influence performance in a highly variable manner.

8. The coding system must be simple and direct; random codes must be avoided. This requires considerable elaboration and will be discussed when the selective calling system is described.

9. The devices should be as nearly all-electronic as possible.

10. The devices must function in the environments to which mobile communication systems are subjected.

BASIC ELEMENTS

Selective Amplifier. The limitation of tone frequencies to the band 300-3000 cps poses a difficult selective amplifier problem. For a solution there are several approaches, each of which have been described in the literature. It was finally decided to develop a feedback type selective amplifier, i.e., a linear amplifier employing frequency-selective negative feedback (a Parallel-T network).

From the literature reasonably useful theoretical analyses were obtained. For a very low-Q circuit the analyses are adequate but for high-Q application considerable additional analytical work was necessary. As a feedback amplifier, the stability problem was complicated by the fact that a Parallel-T network is not minimum-phase and the usual Nyquist criteria do not apply. The stability margins of the amplifier which has been developed are more than adequate to insure reliable operation under all conditions.

In Fig. 1, the selective amplifier is shown schematically. The A-circuit consists of V1a and V2, the B-circuit consists of Z_1 and V1b, with associated coupling networks. At resonance f_0, Z_1 attenuates 90 db or greater, so the full forward gain (approximately 68 db) is attained from V1a grid to V2a plate. The Q of the selective circuit thus formed is approximately 200. The double-triode circuit is chosen for simplicity and relative stability against changes in gain to filament and B+ voltage. This selective amplifier functions very satisfactorily over B+ variations of 100-300V and filament variations 4-8V AC or DC.

It is, of course, obvious that the overall performance of the entire device is proportional to the stability of Z_1. Z_1 is actually a slightly modified parallel-T network which is the result of the major part of the development effort. A large amount of painstaking trial and error plus analytical investigation may be summarized as follows: (See Fig. 2)

1. The physical configuration of the assembly is extremely important, shields and grounds must be properly located to minimize capacity from input to output of the network.

2. Even though there is an apparent gain in selectivity achieved by making the output impedance much greater than the input impedance the most economical and efficient design is actually obtained by making the impedance equal.

3. The resistances must be wire-wound, stabilized types, of as low a value as is consistent with the loading imposed on the circuit. The lower values of R minimize capacity troubles and make possible an unloaded termination.

4. The thermal stability is a function of the ratios $\frac{C_1 + C_2}{C_3}$ and $\frac{R_1 R_2}{(R_1 + R_2) R_3}$. If the thermal coefficients of these ratios are balanced, the device will be stable. The range of variation of the individual coefficient is most important, so the only recourse is to statistical analysis. For the networks we have built to date the net coefficient is normally much less than the 15 ppm/^{o}C maximum.

5. Each network must be tuned to a null which must exceed 90 db at the specified frequency. We have consistently obtained stable 120 db nulls in factory test.

Stable selective amplifiers of the type described have been built to Q's as high as 700 and over the frequency range 300-20,000 cps. For voice frequency tone signalling we have restricted the frequency range to 300-3000 cps and have chosen a Q of 200. This choice of Q is determined by several considerations:

1. The rise time, $\frac{1}{\pi \Delta f}$. should be less than 0.1 second at the lowest tone frequency in use.

2. Within the audio-band the lowest value of Q consistent with reliable operation free of "voice triggering" has been experimentally determined to be approximately 200.

3. Experimentally, it has been found that 20 db rejection of the adjacent tone frequency is satisfactory.

These factors plus the temperature drift consideration establish a spacing of 3% as the most economical of frequency spectrum. The individual tone frequencies are obtained by using 3,000 cps as a base and counting downward, e. g., $f = \frac{3000}{1.03(n-1)}$, where $n \doteq$ tone number. See Fig. 3.

A stable selective amplifier is of little use unless the tone source is of equal or greater stability, particularly since it is necessary to assign a major portion of the system degradation to the devices employed in the mobile equipment.

Two kinds of errors arise in a frequency selective system - absolute and relative differences between the frequency generated and the frequency to which the selective amplifier responds. The relative errors are a function of the thermal stabilities in different environments, but the absolute error may arise from entirely different considerations. If the selective circuits or the amplifiers differ then the processes of tuning, tube replacement, etc., may introduce large absolute errors.

The tone-generator which has been developed embodies a very satisfactory solution to the problems cited. It resembles to some extent the frequency-standard generator described by L. A. Meacham and incorporates the fundamental ideas of Llewellyn. It is shown schematically on Fig. 4A. The salient points

may be summarized as follows:

1. The amplifier V1a, and V2a, operates in a linear manner. The interstage constants are essentially the same as those employed in the selective amplifier.

2. The frequency selective network Z_1 is the same as used in the selective amplifier. It is operated from a voltage generator, into a cathode-follower V1b, and is substantially unaffected by external circuits.

3. The regenerative feedback is controlled by an AGC circuit which yields a very satisfactory negative control characteristic. This circuit characteristic is shown on Fig. 4b.

It will be noted that the output of the generator is a 1 meg. resistor which minimizes any effects of load impedance variation. The generator shown has proven extremely satisfactory for the purpose.

1. The absolute frequency error is negligible.

2. The frequency drift is neglible as a function of plate supply or filament supply voltage variation. In a typical instance the frequency changed approximately 1 cps out of 3,000 when the plate supply voltage was varied from 80 volts to 400 volts.

3. A typical variation of frequency as a function of temperature is given on Fig. 5. Since the selective amplifier is similar we have a good index of the thermal stability of the devices which incorporates these basic circuits.

In the course of testing this tone generator the agreement between theoretical and measured performance was found to be excellent. Due to the statistical variation in components the values cited may be considered typical. Sample checks from time to time show no significant variations.

These two basic building blocks, the tone generator and selective amplifier, have been built in substantial quantities as parts of discrete pieces of equipment. To date no significant variations from predicted performance have been encountered. Application has been made to the following systems.

Selective Dispatch

It is often necessary to signal mobile receivers by group, or service function. Investigation indicated that a maximum number of 10 such groups need be signalled.

The audio signal to perform this function in the receiver is derived from an attenuator which bridges the output of the discriminator. It is thus free from variations due to operator adjustment of volume controls, etc. A short audio signal is applied to a vacuum tube switch which is sensitive to presence of tone and carrier. Simultaneous presence of tone and carrier closes the switch and opens the audio circuits; the carrier then holds the circuit closed. Release of the carrier opens the circuit and reblocks the audio circuits.

The variations inherent in mobile receivers make essential an audio signal approximately 10 db greater than that required to operate marginally with all conditions at normal design centers. This 10 db margin accounts for filament and B+ variations, RF signal level changes, tube and component variations, and temperature drift.

A typical Selective Dispatch system block diagram is shown on Fig. 6. The audio tone selected by the push-buttons is introduced by the C contact in the microphone circuit. Closing the PTT picks up a relay which holds in for approximately 0.5 seconds and then releases. The tone level is adjusted to rated deviation of the system by the only adjustable control in the entire system.

The Selective Dispatch system has been typically used for alerting Volunteer Fire Department receivers which are on the police frequency. Until a fire call is sounded the receivers are silent, then the tone signal opens the receiver and keeps it open as long as required. It has been used to split taxi fleets into area groups, public utility systems into functional groups; any system in which delineation by function improved efficiency and utilization of the radio frequency channels.

Duplex Selective Dispatch

The similarity between the circuits of the tone generator and the selective amplifier would infer that a tone generator could be made from a selective amplifier by completing the regenerative feedback path through an AGC circuit. In the Duplex Mobile selector the path is completed to and from the regenerative AGC by relay contacts. The relay is energized momentarily by closing the PTT circuit, at the same time the microphone circuit is interrupted, and the tone generated is fed into the speech input circuits at proper level. The microphone circuit is interrupted for only one-half second maximum, a negligible amount of lost time. See Fig. 7.

This permits tone signals to be transmitted in both directions and hence a closed system. Skip signals are particularly annoying to low-frequency station operators since station antennae are usually high-gain and well-located. It is not at all uncommon for such stations to suffer continuous interference periods lasting for days. The Duplex Selective Dispatch system permits all receivers in a given system to be silent except when traffic originating in that system is on the air.

Typical applications which come to mind are utility systems which are subject to substantial interference, taxi systems which operate on frequencies whose congestion is unbelievable, and to keep the list of uses under control, Mobile Relay systems.

Selective Calling

In contrast to the previously described group selective system, the selective calling system is an individual selection out of the entire fleet. As nearly as possible, the basic ideas which underlie the telephone system are used, even to the point of "busy-signal" if such is required.

The Mobile Selector contains two selective amplifiers, one is always open and the second is blocked. Two tones are transmitted in proper order of the frequencies to which the selective amplifiers are tuned by the plug-in selective networks. The first tone is amplified by the open selective amplifier, whose output is then applied as an unblocking signal to the second selective amplifier. The second tone is then amplified by the second selective amplifier and applies an operating signal to a vacuum-tube relay stage. The relay then closes alarm, voice coil, or other circuits as required. The possible modes of operations are limited only by the discipline which may be enforced on the fleet. The simplified schematic of Fig. 8 shows the selector.

The distinguishing feature of the Selective Calling System we have designed is the logical method by which the tones are selected and transmitted. There are some 80 tones available in the audio band, which would yield some 6,400 calls. At first glance it would seem reasonable to number the tones and establish arbitrary correlation, such as Car 31 - Code 16 4.
Car 42 - Code 7 27.
Such a random code is neither logical nor is it readily expandable, besides requiring a translation directory in constant use by the operator.

We felt that an approach which leads to a logical direct code must be developed to satisfy all requirements. This is the method:

1. The number of push-button rows in the dispatch selector is the same as the number of digits in the call number.

2. Two of the rows of 10 push-buttons select tones in decimal combination out of a block of ten tones, hence each block contains 100 calls. This establishes the last two figures of the call number.

3. The first push-button row selects the particular block of 100 calls, i.e., it establishes the first significant figure of a three digit code. In case the code is a four digit one, then the numbers selected from the first two rows establish the particular block of 100 calls, the last two numbers making the selection within the 100 block.

4. What is called a diagonal call occurs when the last two digits of the call are the same - it infers that the same audio tone must be transmitted twice in succession. Since this is an unworkable combination a simple artifice is employed. Whenever any push button in the next-to-the-last row is depressed, the tone corresponding to that push button is automatically removed from the corresponding position in the last row, and a diagonal digit is inserted. This corresponds to multiplying by eleven.

On Fig. 9 is shown the fundamental ideas just described.

The basic building block of the dispatching system is the dispatch control unit described and panels of eleven tone generators. Since the two tones are transmitted in sequence the first significant figures of the code may be described in terms of the order in which the panels of eleven tones are picked up. This is accomplished by placing on each panel a relay with 10 A-contacts. Energizing this relay connects the tone generators to the ten tone-lines for

the hold-in period of the relay. This may best be explained by tracing the operation for a typical number. Suppose we wish to call 168, (Fig. 10.)

The digit 1 indicates the panels pick up B A.
The digit 6 indicates selection of the 6th tone in panel B.
The digit 8 indicates selection of the 8th tone in panel A.

Closing the PTT pick up K1 (Fig. 11), K1 picks up K2 which holds in for 0.3 seconds and Panel B is switched into circuit.

K2 relaxes and K3 picks up (for approximately 0.2 seconds) switching into circuit panel A.

The similarity of these ideas to those embodied in telephone-type panel-dial-switching systems has been pointed out as an important consideration. As a matter of interest, the code selection may be readily performed via a dial telephone.

Not obvious is the fact that all tones but the one in use at a given instant are shorted to ground, thus eliminating cross-talk in tone circuits. Since all of the tone panels feed the line in parallel thru the relays previously mentioned it is clear that a great economy in circuits is possible even though as many as 80 tones may be used. The number of tone wire circuits remains constant.

The Selective Calling system has been found to be extremely reliable in actual use over a long period of time. The design has shown itself to be conservative and readily adaptable to variety of receivers.

Tone Operated Switch

The combination of a selective amplifier and a vacuum-tube relay circuit to form a tone-operated switch for individual switching functions has proven to be a very important use. Schematically, one of these is shown on Fig. 12.

The outstanding features of the tone-operated switch are flexibility and simplicity. Switches have been used singly and in combination to perform a wide variety of control and signalling functions. The primary use at the present time is in conjunction with Civil Defense. In this use Civil Defender receivers are tuned to the local public safety frequency and held silent until an alarm is sounded. When an alarm is sounded the relay is energized and alarm sirens, lights, etc., are energized.

One distinctly unusual use has been control vhf equipment over 500 mile carrier telephone circuits using 750 cps as the control frequency. The stable high Q of the circuits has resulted in operation free of voice-triggering and of excellent reliability.

We have surveyed the development and application of a voice-frequency tone signalling system which results from reduction-to-practice of feedback-type selective circuits. These circuits are stable, reliable and economical. The resulting devices are readily adaptable to a wide, and as yet not completely explored, variety of applications.

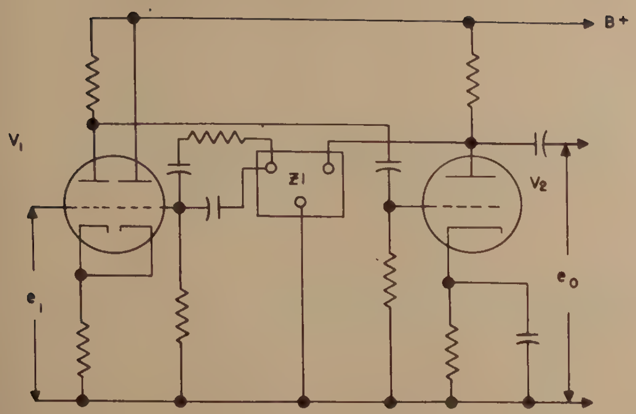


Fig. 1

Schematic of selective feedback amplifier.

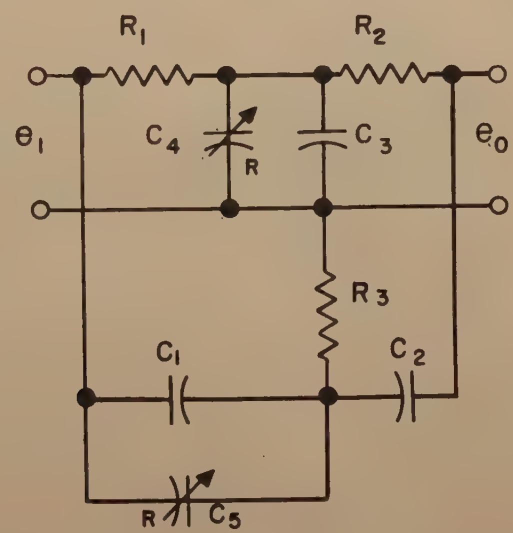


Fig. 2

Parallel 'T' network.

$$W_0 = \frac{1}{R_1 R_2 C_1 C_2}$$

WHERE $R_1 = R_2 = 2R_3$

$C_1 \approx C_2 \approx \frac{C_3}{2}$

$$\frac{C_1 + C_2}{C_3} \cdot \frac{R_1 R_2}{(R_1 + R_2) R_3}$$

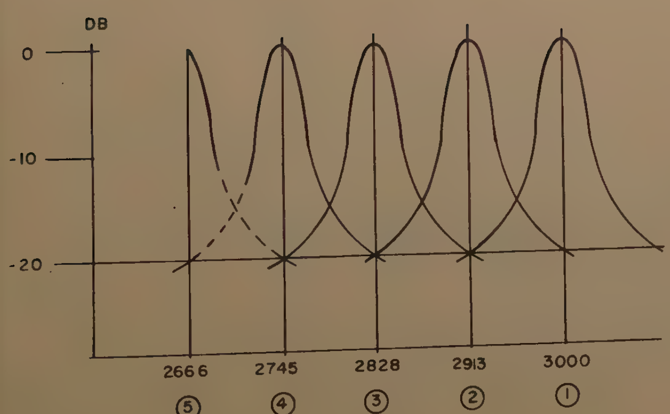
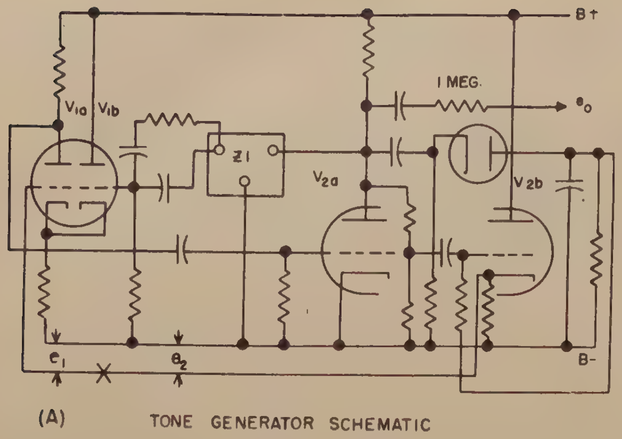


Fig. 3

Arrangement of tones in spectrum.



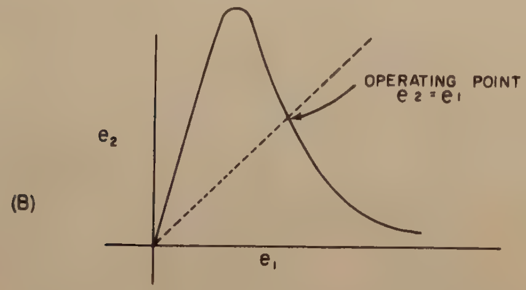
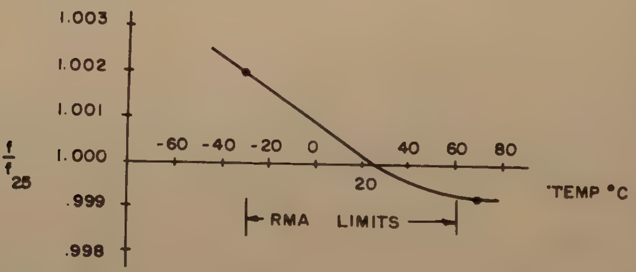


Fig. 4

(a) Tone generator schematic.
(b) Automatic gain-control characteristic.

Fig. 5

Effect of temperature on oscillator stability.



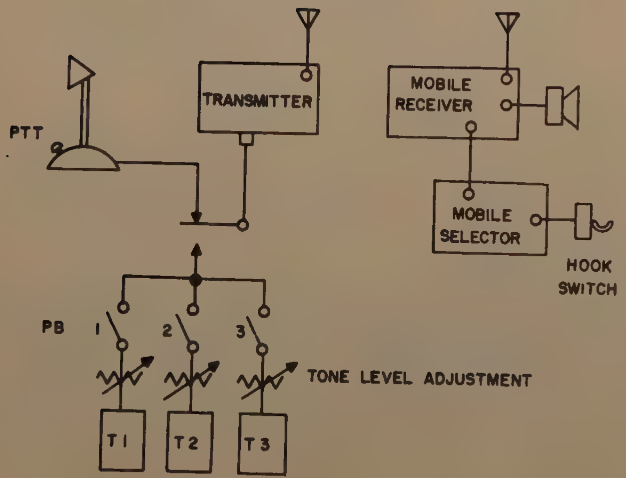


Fig. 6

Block diagram of selective dispatch system.

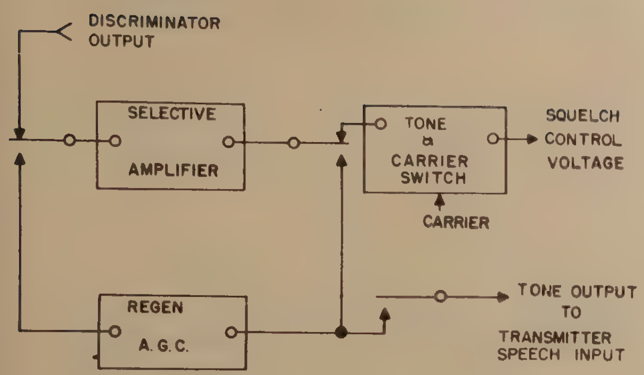


Fig. 7

Block diagram of duplex mobile selector.

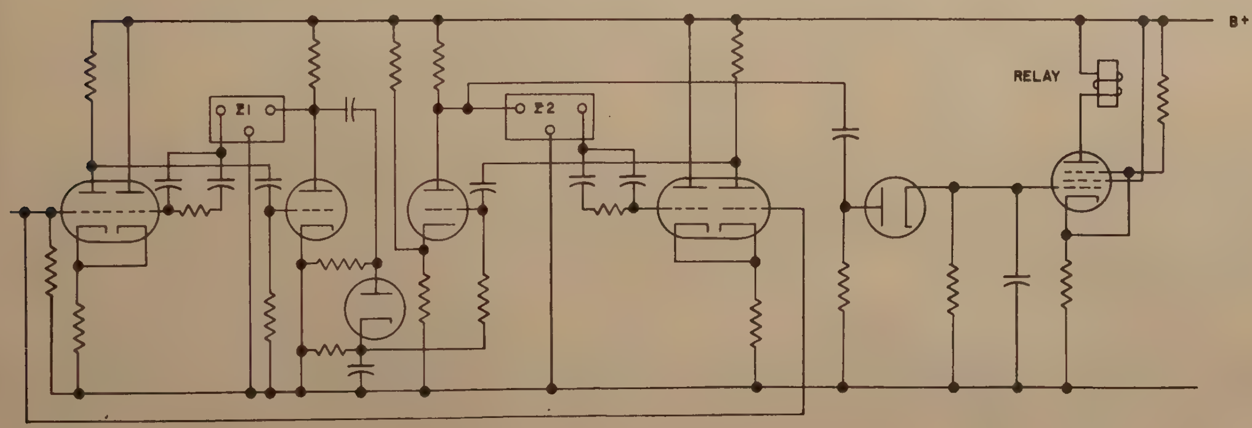


Fig. 8 - Schematic of two-tone mobile selector.

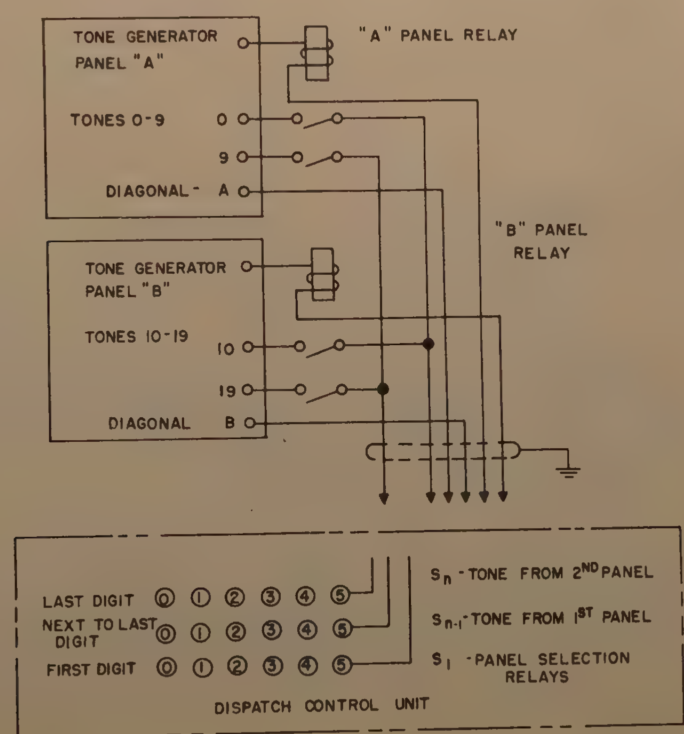


Fig. 9

Block diagram of selective calling system.

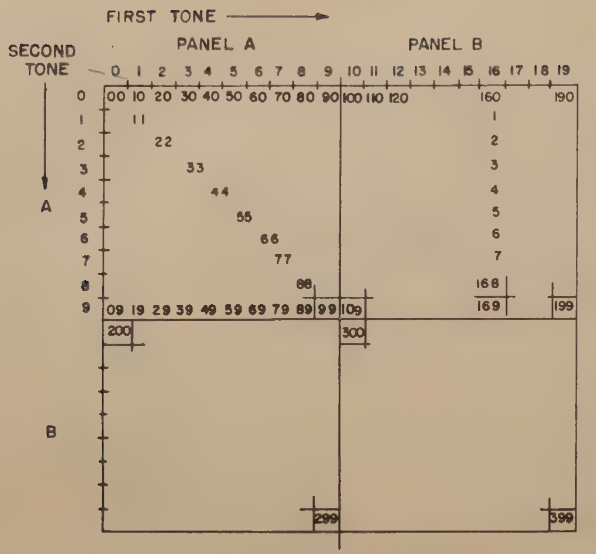


Fig. 10

Sequence of typical call.

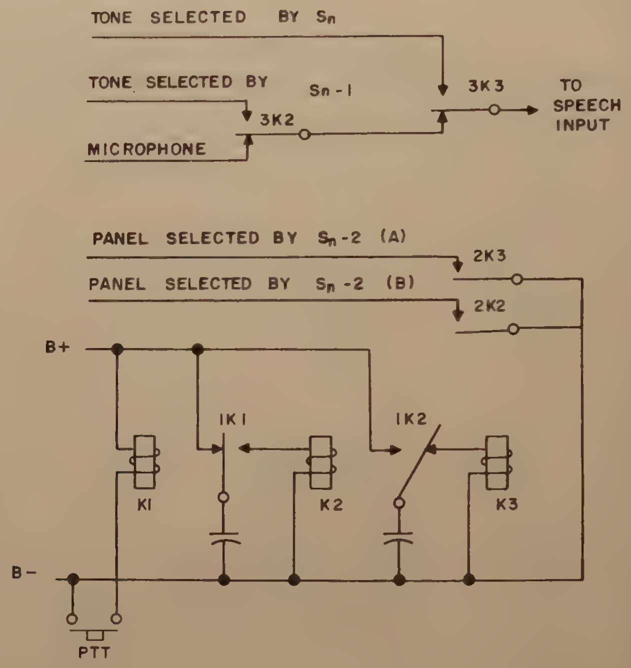


Fig. 11

Basic sequence circuit.

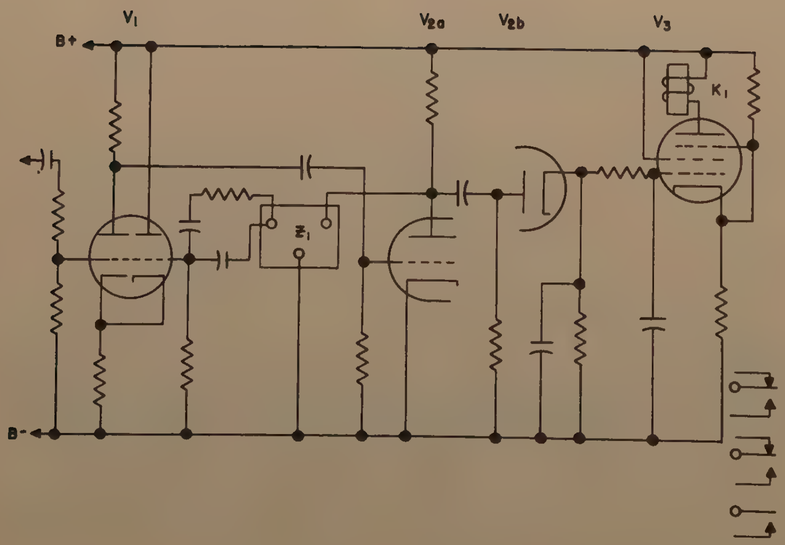


Fig. 12

Schematic diagram tone-operated switch.

A DISPATCHER'S WAYSIDE-TO-TRAIN COMMUNICATIONS SYSTEM

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The title "wayside-to-train" applies to a series of equipments of unitized construction which can be grouped in various arrangements to fabricate a communications system which will permit a dispatcher, or anyone else at one or more central points, to talk directly with the crew of a train regardless of its location along a predetermined territory. The type, variety and nature of these equipments are sufficiently versatile to permit, in the majority of cases, the layout of a system as simple or as complex as an individual railroad desires, without requiring the design and fabrication of special oı "custom" equipment.

In addition to dispatcher-to-train and train-to-dispatcher communication facilities, this system, which utilizes a combination of vhf radio and either existing or additional telephone circuits, provides the added features of local wayside-to-train and train end-to-end communication. The equipment necessary to provide the latter two types of services is being and has been installed in considerable quantity by quite a few railroads during the past seven years. Existing mobile and land station installations can be utilized, with minor modifications, as the radio link required to provide this additional feature. Conversely, the installation of equipment for this new service provides all three services to mobile units and territories not previously equipped.

The original conception of this system was drawn up by Mr. F. L. Steinbright, Superintendent of Telegraph, and Mr. Mitchell Zeller, Telephone Engineer of the Northern Pacific Railroad. Their ideas of what such a system should encompass, suggested ways and means of accomplishing various functions, and provided valuable advice on railroad operating and maintenance procedures which was of inestimable value in formulating the system.

One prime requisite was unitized construction with quick disconnect and replacement feature. The reasons for this were severalfold; one was that from the maintenance standpoint it was more practical to change out a faulty section in the event of trouble rather than having to trouble-shoot and make on-the-spot repairs. This enables less experienced personnel to restore service quickly while the faulty section could be serviced at a central location where competent technical personnel and equipment were available. A second reason was that in the unitized or building block style of construction, a system could be installed providing only limited functions and could be expanded at some later date to provide additional facilities without obsoleting that portion already installed. The third reason, which already has been suggested, such a design would be adaptable to the requirements of any other railroad.

Before proceeding with a detailed account of the original specifications and how a system was engineered which satisfies these specifications, a limited review of railroad dispatching methods and practices is in order for those who may not be fully acquainted with the problems involved.

There are in use on all American Railroads today two basic systems of train dispatching. The first and also the oldest, as well as the one still in greatest use, is termed the "Train Order System". This method, usually conbined with a system of block signalling and interlocking plants, utilizes a series of waystations with attendants interconnected to a dispatcher located at some terminal point by means of a telephone circuit. This telephone circuit, or in some few cases a telegraph circuit, is privately owned and operated by the railroad. It takes the form of a local battery, multiple drop party line. It may have anywhere from ten to hundreds of phone sets connected to it, with one in every waystation and very often in booths placed strategically along the right of way. It is invariably of open wire construction and the dispatch channel may be telephone carrier for a portion of its distance, or the line may have carrier for other circuits superimposed on it in addition to being a voice channed for dispatcher purposes. It may be part of a phantom. It very probably is already simplexed or composited for additional telephone or telegraph purposes.

The orders and instructions necessary to maintain an efficient and safe flow of traffic over a division or subdivision of the railroad are passed from the dispatcher, by voice, to the various waystation attendants who act upon them and deliver them to the crews of the trains in their particular sections. Requests for instructions or clarification of an order are passed from the crews to the dispatcher back over this same circuit. Phones along the right-of-way provide additional points from which trains can report breakdowns or other information to the dispatcher. These waystations are in some cases manned 24 hours a day, but quite frequently only 8 or 16 hours a day. They are so spaced along the right-of-way so as to make certain ones ideal locations for land station sites for the radio system. Systemwise they must be carefully selected with the aid of contour maps and the application of propagation formulas to provide slightly overlapping, 100% coverage of the right-of-way.

The addition of facilities to permit two-way direct communication between a dispatcher and the crew of a moving or standing train by combining the existing telephone dispatch circuit with V.H.F. radio is of unquestionable value to a railroad in expediting traffic where this form of dispatching is being used.

A newer system already in considerable usage and rapidly being expanded to additional territories is known as C.T.C. or "Centralized Train Control". In this system a dispatcher located at some central point, not necessarily along the railroad, is seated at a console upon which are mounted control switches and indicator lights for every track switch and signal tower along a given section. On a display at the top of this board, indicator lights give him the constant progress of each train along his division. This modern method of control utilizes coded signals initiated by the action of a switch on the control console and transmitted over a form of telephone carrier. The proper signal or switch along this telephone circuit automatically responds to this coding and initiates the desired action. The action properly completed automatically codes a reply back to the control console to the appropriate indicator light. In a similar manner, trains passing a certain section initiate codings back to the control console showing their position and progress.

This method of dispatching has greatly reduced the need for attended waystations for relaying orders, and therefore made more difficult the problem of

communication between a dispatcher and the trains. The need for a system which permits automatic direct communication therefore is, if anything, more acute with C.T.C. than with train order dispatching. A light on the dispatcher's console will indicate to him that a train has stopped at a certain point, but will not tell him necessarily "why" or "how long", and a train crew foreseeing difficulties can, if they have some means of direct communication, report it and receive instructions from the dispatcher as to what to do or where to proceed to cause the least interruption to other traffic.

In both types of dispatching we have, therefore, circuitry which can be utilized to carry a voice circuit from the control point to selected land station sites along the right-of-way. There are also available along the same routes additional phone circuits known as message circuits to differentiate them from dispatch or C.T.C. circuits; however, unless specifically demanded by a particular road, they are not usually considered for dispatcher-train purposes because they are usually available to anyone or everyone who wishes to chit-chat up and down the road and are invariably occupied when they are most needed.

It must be apparent to everyone that since any system of train dispatching depends almost completely upon private line circuits, any interruption of these circuits can greatly hamper, if not stall, a whole division. Thus any added system or facility which provides an emergency network to bridge a line break and maintain communication is a very welcome addition, particularly for territories where sleet, winds or other acts of God frequently cause line prostration.

The Northern Pacific Railroad, which has for some years been very progressive in the adoption of vhf radio for train end-to-end and local wayside-to-train communication, as has been stated drew up tentative specifications and suggested methods for the development of a flexible integrated system providing a reliable communication circuit between any equipped train and a remote location. Their requirements were that the standard dispatcher's circuit be used as the connecting link to the various waystation radio sites and that since a number of these waystations are unmanned during a greater portion of a 24 hour period, the system had to be completely automatic - automatic meaning the dispatcher could select the waystation radio nearest the particular train he wished to communicate with, select the desired radio channel and key the transmitter. Also, a train desiring to initiate a call to the dispatcher would be provided with means to connect via radio the nearest waystation to the dispatcher's circuit.

From their viewpoint and in the interest of economy, it was desirable that some time delay circuitry should be incorporated to hold a waystation on the dispatcher's line for a predetermined period of time after a call was initiated by the train. By this method it would not be necessary to provide indication to the dispatcher through which waystation radio the call had been received, and he could answer, hold or allow to drop back off his dispatch line that intercepting waystation in the event he has been busy, without resorting to his own dialing or station-selecting equipment. In this version of the system, a dispatcher receiving a call from a train can throw a switch which will connect up the circuits necessary to send out the coded pulses which will put the connected waystation transmitter on the air and answer the call, or at least allow

the train to hear that he is busy talking to some one else, yet hold the waystation radio on the line. Or, he can ignore the call by not activating the circuits which send the coded pulses, in which case the waystation will drop off his line after a short interval. This approach is described because it is a unique, but simple solution to one of the problems of such a system resulting in a considerable saving in equipment, although of course a call indication or busy signal arrangement can be provided.

The dialing up or selection of the desired waystation radio by the dispatcher initiating a call had to be positive and simple and there was nothing better suited for that purpose, and more economical than the facilities in use on every railroad telephone circuit. I refer to the use of standard railroad selectors at each waystation site, permitting the dispatcher to dial-up or dial-off a particular radio station from a selector set he already has installed for the purpose of ringing up the numerous phones along his line. Of course a selective calling system utilizing selective tones to accomplish the same result could be incorporated but will only result in increased cost and complication.

For a call originating from a train, this selector system was not practical since it is principally designed for use over land lines where $3\frac{1}{2}$ cycle dialing impulses can be easily transmitted. A simple system of single pulse tone transmission from a special mobile control box on the mobile unit or train is all that is necessary to make the connection in this system when the call is originated by the train.

The operating functions themselves, such as press-to-talk and channel change, which are obviously required to effect the control of a land station over a pure voice circuit, are adaptations of a pulsed tone selective calling supervisory control system developed simultaneously with this equipment. A single or a combination of pulsed tones of various frequencies in the range of 250 to 500 cycles and of approximately 250 millisecond duration are transmitted over the telephone circuit from the dispatcher to the wayside radio station to perform these functions.

The selective reception of these tones is accomplished with resonant reed relays which, in some instances, directly actuate controlling relays and in other instances work through vacuum tube circuits to perform the required function. In general, one, or a coincident group of pulsed tones are required to initiate an action such as placing the transmitter on the air, and a second individual or group required to restore the radio equipment to a receive or standby condition. Extensive tests demonstrated that with the use of resonant relays in place of electrical filter circuits, it was possible because of their extreme selectivity and power integrating characteristics, to guarantee practically 100% against the possibility of spurious or accidental triggering. These resonant relays which are accurate over a wide temperature range will respond at their nominal input of 35 ampere turns to frequencies not removed more than ± 5 cycles of their center frequency and are calibrated to within ± 1.5 cycles of their specified frequency. Where the quantity of functions makes it impossible to use a different single tone for each OFF and each ON action, a coded system of multiple tones is more suitable. Another application in which single control tones have not proven practical is where the circuit is partially or completely over a carrier telephone channel in which case the permissible shift in audio frequency, as a function of the carrier modulation

and demodulation, is greater than the resonant relays accept, and therefore a series of tones must be transmitted and the resulting difference beat frequency, which does not vary with fundamental frequency shift, be utilized.

Unitized design was accomplished by carefully analyzing the various individual functions of the system as an entity after the overall design was stabilized and breaking them off into individual plug-in subassemblies. For example, the compressor amplifier obviously is a "must" to guarantee a workable audio level to frequency sensitive control units, transmitter modulation circuits and waystation sidetone loudspeakers, when working from a telephone circuit that can vary from time to time on a particular installation over a range of 20 db. A second subassembly is the line bridging unit which contains the bridging transformer and the mechanical latching relay which connects the dispatcher's circuit to the equipment. This connection is made as a result of the operation of the standard railroad selector, a switch on the waystation local control unit, or in the case of an automatic waystation, by the proper tone from the mobile transmitter.

A frequency selective relay unit for each ON and OFF function to be accomplished remotely over the telephone circuit was still another building block. Of course the quantity required depended on the functions desired.

A power supply capable of handling up to the most complex installation and providing filament plate and relay power for the waystation control equipment was obviously a complete subassembly.

A matching unit to terminate the waystation control and audio circuits to an adjacent radio communication unit is still another which can be substituted with still a different unit if the communication unit itself is separate from the waystation equipment, such as on a hill or a tall building, and controlled over a local telephone circuit. In this application the control circuits from the waystation to the communication site can be of the simplex, composite or metallic loop variety over the connecting circuit, having been transcribed from tones to dc at the waystation or the same pulse tone system utilized over the dispatcher's circuit can be continued to the communication site for control purposes.

Where the waystation is of the unattended variety, permitting automatic signalling of the dispatcher from a train, at least one and usually two additional subassemblies are included. The first of these is a frequency sensitive device which acts on a single tone in the range of 1,500 to 2,800 cycles and transmitted from the train to connect the waystation communication unit to the dispatcher's line. The design of this unit is such that once the connection is made, and as long as there is communication passing through the waystation equipment, as indicated by receiver unsquelching or transmitter ON action, and for a selected interval after the interchange has been completed, the connection will continue. After this interval has expired, the waystation is automatically disconnected again from the line. The companion subassembly known as a "lock-out unit" is for the purpose of deactivating this automatic disconnect feature when the waystation is dialed on the line by the dispatcher or connected by the local attendant. Of course where the drop-out feature is desired, regardless of how the hook-up originated, this additional unit is deleted.

The dispatcher's control equipment is likewise of the same building block principle. For each function he is to control over the circuit, there is a chassis which provides highly stable tone-generating and pulse-keying circuits. The same type of power supply unit which powers a waystation installation is used at this location.

The only portion of the system that must be strictly custom-built is the intercabling required to combine the necessary complement of subassemblies into an installation. A number of packaging arrangements have been made available. One is a completely cabled and enclosed cabinet which can house a communication unit as well as all control subassemblies. Another version is an intercabled frame for the units which permits their mounting in a standard relay rack. There are also smaller enclosures which will house individual units or small grouping for simplified installations.

Unfortunately the time limitation on this paper does not permit me to delve too deeply into a technical description of the operation of all phases of the equipment. Nor does it allow me to outline all the variations and complex control circuitry involved in a number of existing installations. I would like to say, however, that two railroads, the aforementioned Northern Pacific, and the Milwaukee Railroad now have territories equipped with this system, and its performance has equalled, and in many ways exceeded, highest expectations.

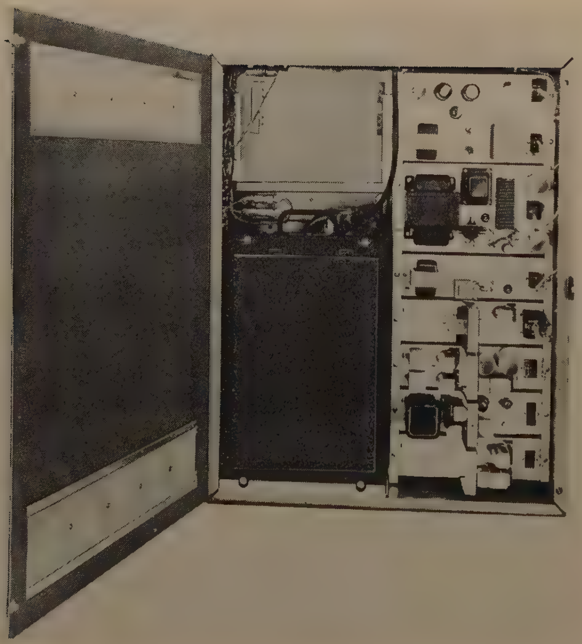

Fig. 1

Complete unattended waystation including radio communication unit mounted in an MM-64A housing.

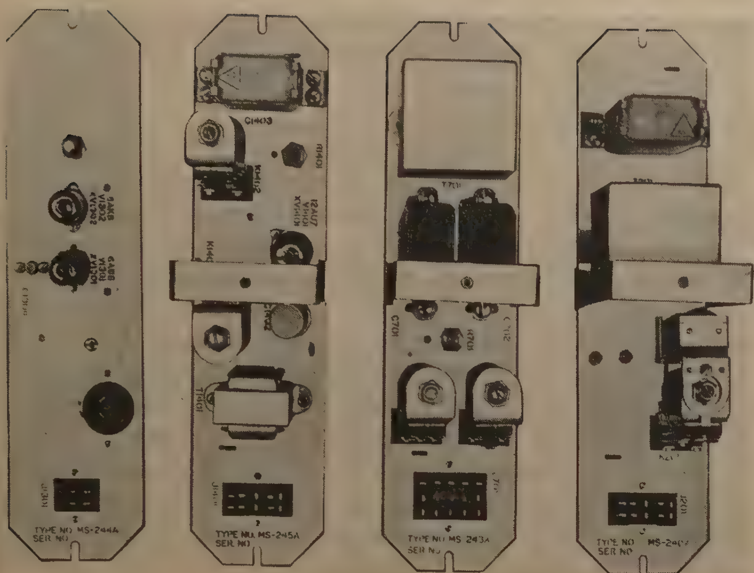

Fig. 2

MS-240A line bridging unit
MS-243A line termination unit
MS-245A line keyer
MS-246A dispatcher oscillator.

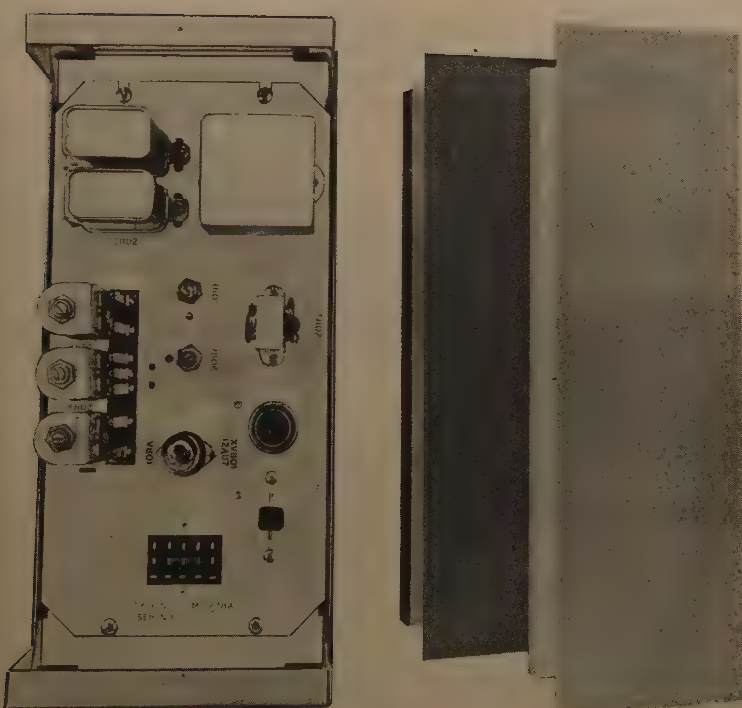

Fig. 3

MS-238A line termination unit mounting in MM-69B individual unit housing.

NEW DEVELOPMENTS IN ARMY MOBILE COMMUNICATION EQUIPMENT

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In 1945 the operation of vehicular and field equipments in World War II was carefully analyzed and military characteristics for a new series of vehicular equipments established. The primary improvements over World War II equipments considered necessary were: reduction in the number of crystals required; more flexibility of channel assignment; complete immersionproofing; and capability of operating from storage batteries or from hand generators and dry battery sources in the field. The new equipments developed to meet these requirements, Radio Sets AN/GRC-3 through 8, are comprised of various assemblies of a group of major standardized components. Vehicular equipments to meet various communication needs may be assembled from these components on a building block principle. Each of the components and the acoustic accessories have been made immersionproof, this much-needed protection that was found necessary to attain reliability under tropical conditions. The equipments are designed for operation over an ambient temperature range from -40°C to up to 65°C.

The radio sets utilized are frequency modulated and cover the frequency range shown in Fig. 1. This frequency range is divided into 100-kc channels:

20-27.9	80 channels for the Armor
27-38.9	120 channels for Artillery
38-54.9	170 channels for Infantry elements.

Ten overlap channels are provided in each frequency range. The major item of this equipment is the medium powered transceiver shown in Fig. 2.

This transceiver is referred to as the "A" set. There is one in each of the frequency ranges used by Armor, the Artillery, and the Infantry Arms of the Services. All of these transceivers are physically identical with the exception of the frequency determining elements, the basic objective being the simplification of maintenance, reduction in specialization in operator training, and reduction in the number of spare parts required to be kept in stock. The unit is a transceiver in order to make possible maximum utilization of components. Both receiver and transmitter are placed on frequency by the two front panel knobs. Dials affixed to these knobs read the frequency directly. The so-called megacycle dial on the left reads whole megacycles and the knob on the right, tenth megacycles. For 21.5 mc, for instance, one dial is set to 21 and the other to 5. A detent mechanism is built into the tuning system so that the knobs stop at each 100-kc channel. This detent system may be released to permit continuous tuning between channels if desired. Operation of these knobs tunes all of the RF circuits, including the antenna. The transmitter portion has an RF power output of between 15 and 20 watts over the frequency range. The receiver has a sensitivity of 3/10ths of a microvolt for a 10-db signal-plus-noise-to-noise ratio. The IF bandwidth is 80 kc at the 6-db points. The unit uses one crystal for each megacycle of tuning range and all are self contained. The power supply is not self contained, but is provided as a separate component.

The next item is the auxiliary receivers (see Fig. 3). These are of the single conversion superheterodyne type and are equivalent in performance and selectivity to the receiver of the "A" set previously mentioned. There are also three of these items, one in each of the frequency ranges, and the receivers are identical in all respects with the exception of their frequency determining elements. They have self-contained vibrator plug-in power supplies.

The "A" set and this auxiliary receiver are connected in parallel to a single antenna on the vehicle. An antenna relay in the transceiver opens the receiver circuits while transmitting. The receiver is continuously tunable from the front panel and has a built-in means for calibrating the dial, which is accurately marked in 100-kc channels. Three preset positions are provided. They may be set up anywhere in the frequency range through the waterproof cover on the front panel. Slight adjustments to the detented position may be made by adjustment of the knobs in the upper right-hand corner. Correction of a detented channel by these knobs does not affect the accuracy of the other detented channels or the dial calibration. A squelch circuit for silencing the audio output in the absence of signal is provided. Adjustment of the squelch threshold and sensitivity may be made at the front panel.

The next item is a low powered transceiver, the so-called "B" set (see Fig. 4).

This transceiver covers the range 47 mc to 58.4 mc. It also utilizes frequency modulation and is designed for 100-kc channel operation. It has an RF power output of 0.3 of a watt and a highly sensitive receiver comparable to the other receivers already mentioned. Two detented channels are provided. These may be adjusted from the front panel anywhere in the frequency range of the set. A squelch circuit and a built-in calibrator, which gives a calibration point at each megacycle point, are also provided.

The next item is an interphone amplifier and power supply (see Fig. 5). This unit is a three-channel audio amplifier, one channel output being approximately 1 watt and the others, 250 milliwatts. It is used to mix properly and impedance match the radio equipments to various control boxes within the vehicle and to provide an interphone system by means of which the crew members of tanks and other vehicles may carry on local communication required for operation of the vehicle and other tactical functions. This unit includes a plug-in type power supply for the previously mentioned "B" set. Three types of vibrator supplies for 6-, 12-, and 24-volt operation are provided.

Both the auxiliary receiver and the interphone amplifiers utilize the same type of plug-in supply.

The next item is the "A" set Power Supply. Two types of "A" set power supplies are provided, one for 12-volt input, and the other for 24-volt. Both use vibrators exclusively and include a means of regulating the filament supplies of the "A" set.

Military vehicles are now standardized on a 24-volt ignition system, and most of the supplies being bought for the future are 24-volt type.

Various types of shock mountings are provided which correspond to the number of components which may be required for the particular application. A typical mounting for a complete radio set includes facilities for properly clamping the equipments and a compartment with terminal facilities for interconnecting the various items.

Fig. 6 shows a complete set with a maximum number of components. A section is provided in the mounting base for plugging in a component known as the retransmission control. This control is designed to provide retransmission facilities as follows: Since both the "A" set and "B" set have squelch circuits which operate in accordance with application of signal, these circuits are used to operate sensitive relays in the retransmission control unit. These relays are arranged to switch the output of one transceiver to the input of the other and put the carrier on the air.

Fig. 7 is a block diagram of retransmission operation. The unit in the lower right-hand corner may be one of our small portable or pack equipments with a communication range of one to three miles. The middle equipment may be mounted in a vehicle and the equipment in the upper right may be at a command post 10 or 15 miles away. Then, by means of the retransmission system, the small pack equipment has the full facilities and range capabilities of the high power equipment mounted in the vehicle. There are many requirements for a unit of this type when the vehicular equipments arrive at a point from which they can advance no further. Forward observers and scouting parties having the lightweight equipment are then sent out, and communication from these far forward elements to the command post may be effected without loss in time and the error often attendant to oral repeating of messages, since the retransmission, after being properly set up, is entirely automatic.

A meter and suitable volume controls are provided on the retransmission unit so that the audio modulation level may be properly adjusted in both directions. Lights on the front panel indicate the direction of retransmission. Monitoring and break-in facilities are provided for a local operator.

Remote control facilities for operation of the complete radio set assembly at distances up to 2 miles are also provided.

The local control is plugged into the mounting base in the position normally occupied by the retransmission unit and the remote control unit is connected to it via a two-wire telephone line. Selection of either "A" set or "B" set transmission and continuous monitoring of the "A" set and "B" set is then possible. Regular telephone communication between the radio set and the remote location, with ringing and signalling facilities, is also provided.

Control of the complete radio set at various positions in the vehicle is achieved by means of a standard control box. This control box has three positions. A space is provided above the selector switch for writing or stamping in of the actual frequencies or code names of the military organizations in the communication net. Each control box has connections and volume controls for two vehicular crew members. Regardless of the position of the selector switch, all crew members are in interphone communication. With the selector switch in the mid position, the output of all radio receivers is

monitored: in the left-hand position, the "A" set only; and in the right-hand position, the "B" set only. Headsets and boom microphones are provided in the armored vehicles and a chest set is used for selection of either interphone communication or the desired radio transmission.

As was mentioned previously, the equipment was designed for minimum power input and weight so that field operation with dry batteries and a hand generator is practicable.

The "A" set may be removed from the vehicle and carried to the desired field location with a suitable carrying bag which is provided. Communication may then be established with approximately the same range capabilities as obtained in a vehicle. The battery supply operates the receiver on standby and the hand generator is cranked to generate the proper voltages for transmit. In case of nonavailability of batteries, the equipment may be operated directly from the hand generator on both "receive" and "transmit".

In addition to the vehicular equipment already described, an intensive program of development of portable equipments has been recently concluded. The most important of the portable type sets are Radio Sets AN/PRC-8, 9, and 10. There is one of these in each of the frequency ranges for Armor, Artillery, and Infantry, as with the vehicular combinations. These radio sets are portable transceivers with a communication range of 3 to 5 miles. They weigh 21 pounds, complete with 24-hour battery and necessacry accessories, (see Fig. 8).

They, too, are also identical in each of the frequency ranges, with the exception of their frequency determining elements. The set is 18 inches high, 9 inches wide, and 3 inches thick. It is completely immersionproofed and its form factor was selected as being most adaptable for back pack carrying.

The radio set is completely sealed from the battery box and the battery box, in turn, completely sealed when fastened to the bottom of the radio set proper.

These equipments tune the frequency range continuously and they are also designed for 100-kc channels, making netting with the vehicular equipments possible. A built-in calibrator is provided and calibration points are available at each megacycle point. The equipment includes squelch circuit and squelch operated relay, and retransmission between two equipments is possible by connecting two sets back-to-back via an interconnecting cord which may be attached onto the audio jacks. All of the equipment contains a new type immersionproofed audio jack with butt type contacts. All connections of the jacks have been standardized such that it is possible to connect a handset, single microphone, single headset, chest set, or loudspeaker, the proper connections being automatically made. The equipment includes a short antenna, approximately 36 inches long, for use when man packing the equipment. A long antenna, approximately 9 feet long, is provided when longer range from a fixed location is desired. A coaxial fitting is provided so that a loop antenna may be attached for homing facilities.

The set contains 16 tubes, all being subminiatures, with the exception

of the transmitter stage, which is a jumbo miniature type. The unit is a transceiver with a single conversion superheterodyne receiver and a single stage oscillator amplifier transmitter which is frequency modulated.

These equipments include plug-in IF stages complete with their subminiature tube. They are easily removable for maintenance. Easily removable stages are also provided for the individual transmitter oscillator, first RF mixer, etc. Each of these stages is individually constructed and tested and is connected into the equipment by approximately five solder connections. Equipment of this type, which utilizes miniature construction, has made it necessary to make every effort to improve maintenance capabilities, and in this particular equipment, two approaches to this basic problem, utilizing of unit stages, have been carried out. Experience to date in both production and maintenance has indicated very satisfactory results.

Fig. 9 shows the set in use on a soldier's back. The holster type bag at his side contains the operating manual, the folded up long antenna, and the handset when not in use.

In addition to back pack type equipments, a hand held radio set is an important item in our forward area communications scheme. The most recent unit of this type is Radio Set AN/PRC-6, shown in Fig. 10.

This is the complete radio set with self-contained battery and microphone and earphone. A 24-inch antenna is furnished. The equipment has a communication range of 1 mile. It is also FM, of the proper characteristic to net with the portable and vehicular sets already mentioned. A standard connector is provided for external handset operation if desired.

The transceiver contains 14 tubes. All are subminiature, except the transmitter output tube, which is a miniature type. It is a transceiver type circuit with a crystal controlled single frequency superheterodyne receiver with AFC controlled transmitter. It is preset on one channel. It may be set to any 100-kc channel in the frequency range 47 to 55 mc. A kit of crystals is provided so that the desired channel may be set up prior to the tactical operations. The equipment weighs $6\frac{1}{2}$ pounds, complete with a 24-hour battery. It has a cast magnesium case and is completely immersionproof.

The equipment is tuned to frequency by small plastic Geneva countermechanisms which are attached to the RF tuning elements. A calibration chart is provided so that the unit can be set approximately to frequency by the counter numbers. A hermetically sealed discriminator transformer is provided for the AFC circuit controlling the transmitter.

The equipment which I have so briefly described is the result of the cooperative efforts of the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey and many civilian communication organizations and private individuals, among them the Bell Telephone Laboratories, the RCA Manufacturing Company, the Raytheon Manufacturing Company, and the Federal Telephone and Radio Corporation.

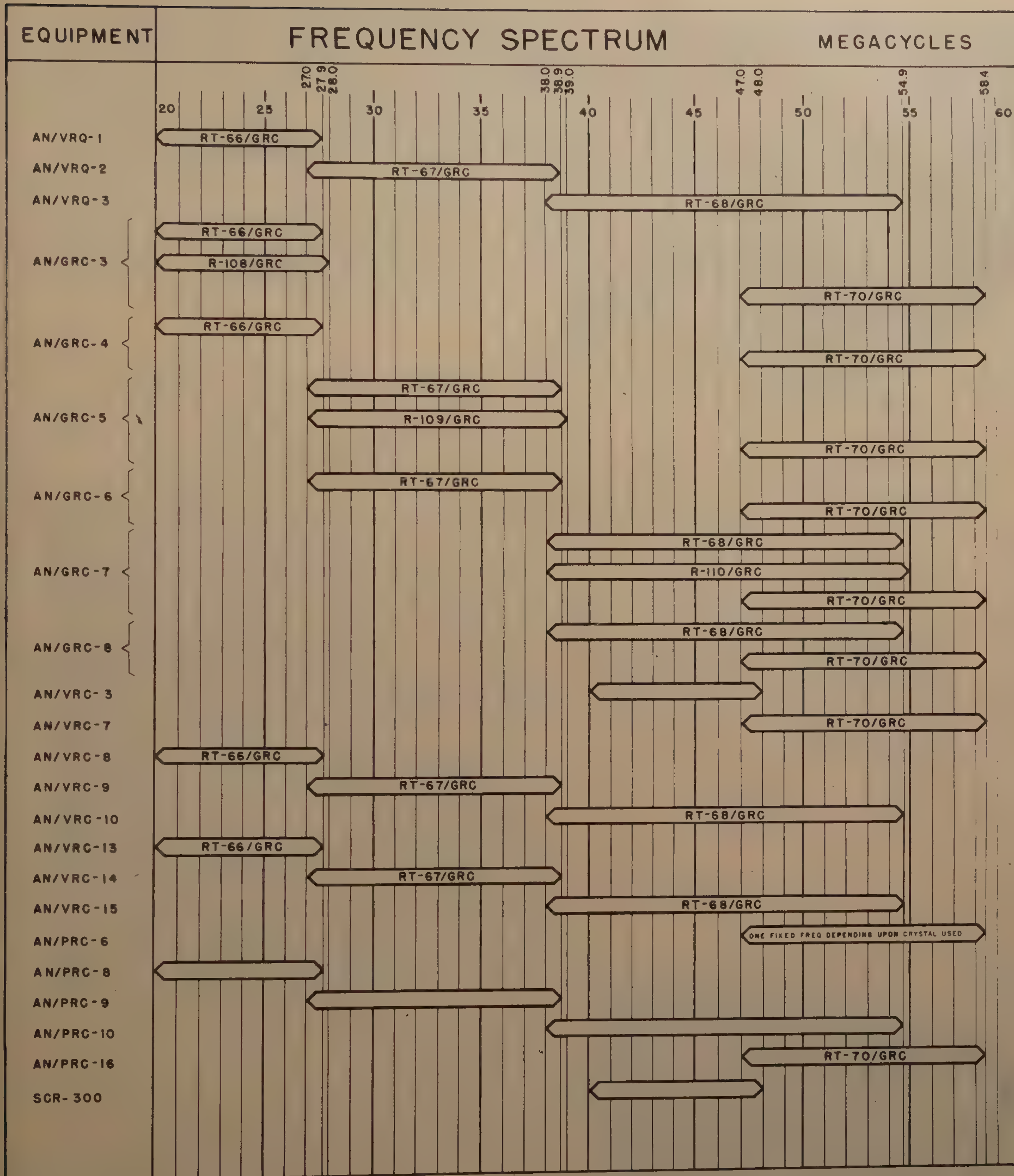


Fig. 1 - Frequency ranges of communication equipment.

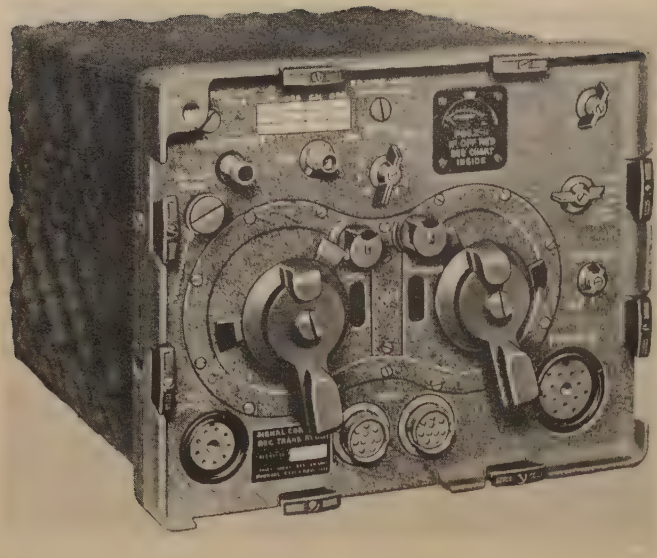


Fig. 2 - Medium-powered transceiver.

Fig. 3 - Auxiliary receiver.

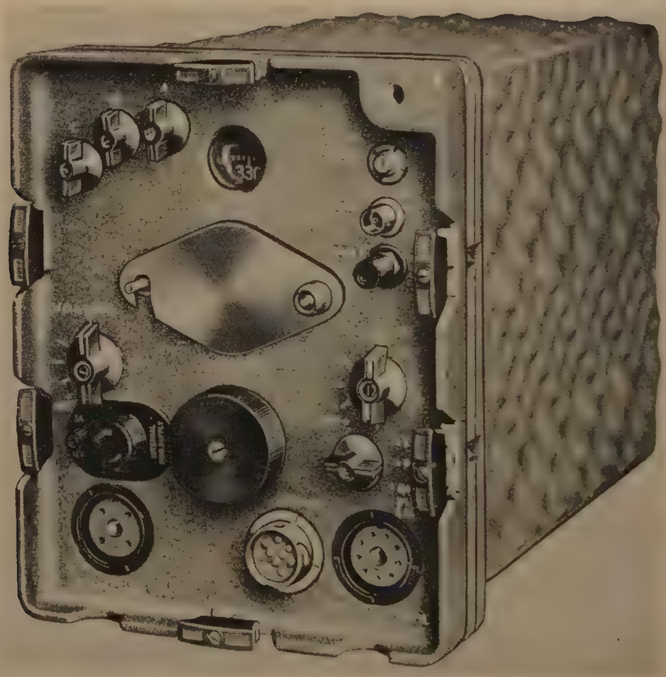


Fig. 4 - Low-powered transceiver.

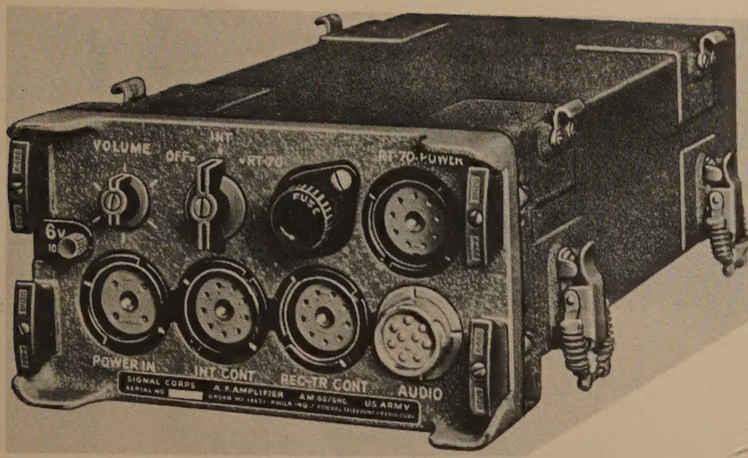


Fig. 5

Interphone amplifier and power supply.

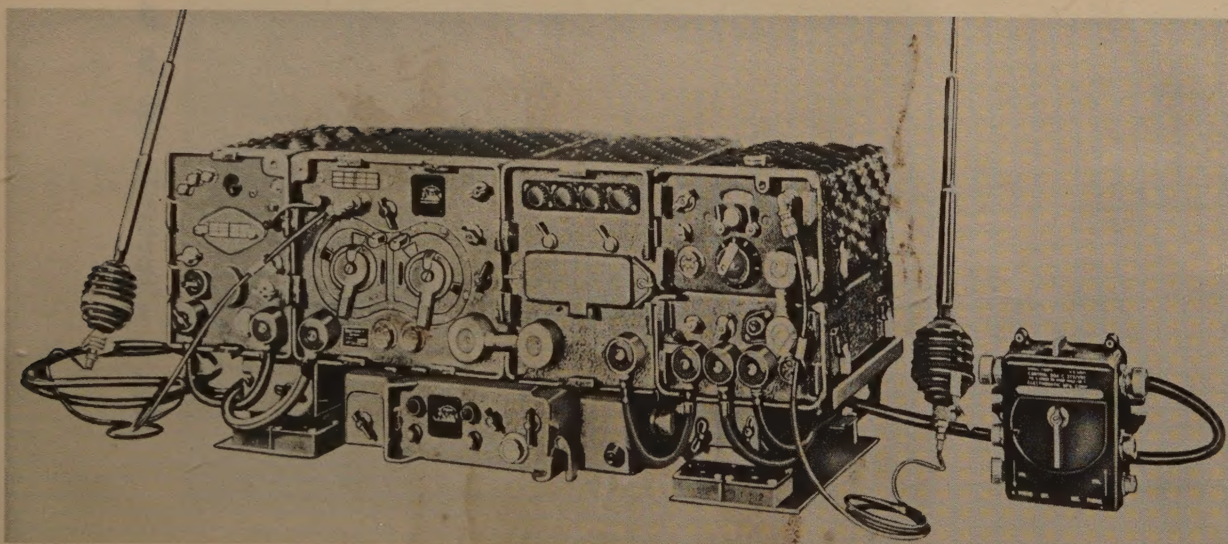
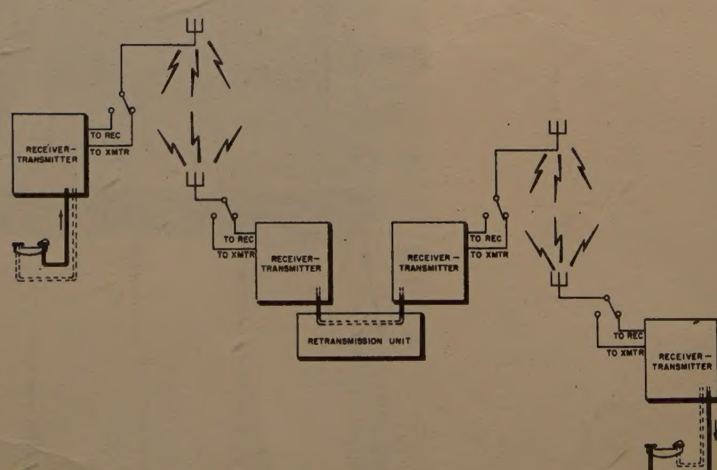


Fig. 6 - Complete radio set.

Fig. 7

Block diagram of retransmission operation.



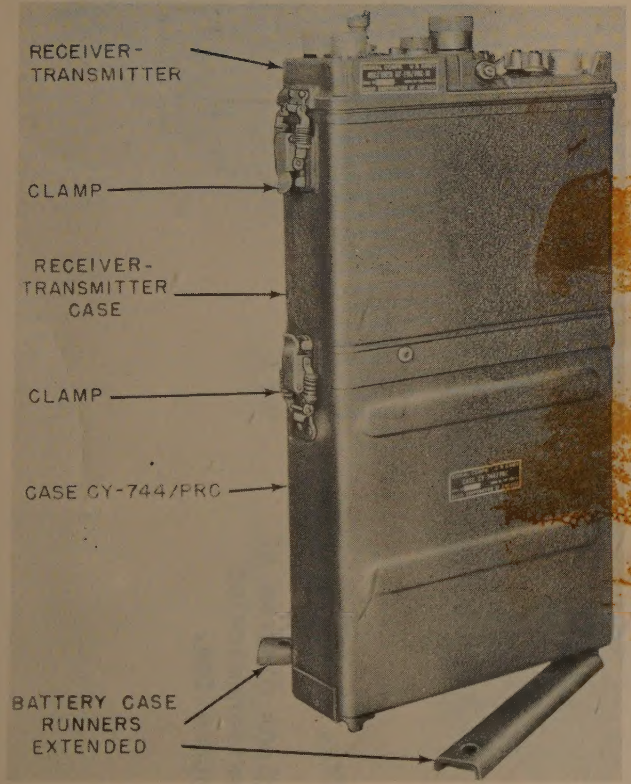


Fig. 8 - Portable transceiver.

Fig. 9 - Portable set in use.

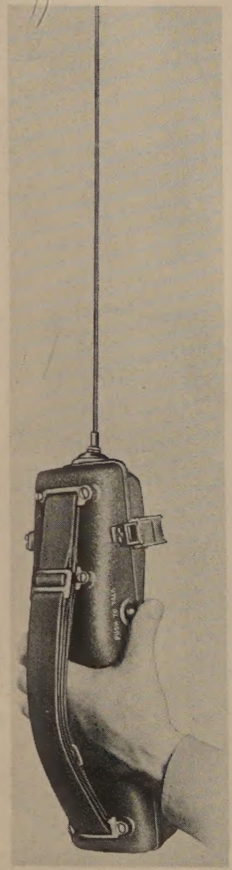


Fig. 10

Hand-held radio set.